Fermi National Accelerator Laboratory

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CDF and D0

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Abstract

CDF and D0 have collected a huge number of B meson during the 1992-1993 collider run. The major results on B lifetimes, rare decays and $B^0 - \bar{B}^0$ mixing will be here reviewed. The first measurement of time dependent mixing at hadron collider is also presented.

1 Introduction

B physics has become one of the major items that can be studied at hadron colliders. CDF and D0 have exploited the large b production cross section (on order of 50 μb at Tevatron energies) through lepton signature. The requirement of an high transverse momentum (p_t) lepton selects B hadrons through semileptonic decays quite efficiently.

With these data samples it is possible to make several measurements which constitute a good test of the Standard Model. In particular, the decay properties of the heavy mesons give insight into the weak mixing angles of the quarks.

In this paper results from the 1992-1993 Tevatron Collider run are reviewed. The CDF data sample consists of about 19 pb^{-1}, while the D0 one is of 13 pb^{-1}. Detailed description of the CDF [1] and D0 [2] detectors can be found elsewhere. The topics covered include the measurement of neutral and charged B lifetimes and B_s lifetimes (CDF), limits on B rare decays (CDF), time integrated $B^0 - \bar{B}^0$ (CDF and D0) and the first measurement of time dependent mixing at hadron colliders (CDF).

2 Lifetimes measurements

The Standard Model describes B mesons decay through the so called “spectator diagrams”. A difference of 5-10% between B_u and B_d lifetime is expected while B_s lifetime is predicted to be very similar to B_d.

2.1 Charge and neutral B lifetimes measurement

At CDF, the measurement of charged and neutral B meson lifetimes was performed using fully reconstructed $J/\psi K$ events, [3] providing a statistical precision of 10-12%. The same measurement can be done using semileptonic decays. Partially reconstructed decays $B \to l + D^0(D^{*+}) + X$ where $l = \mu$ or e provide us nearly orthogonal samples of charge and neutral B mesons. If there are no D^{**}'s involved in the semileptonic decays, the following are the only lepton-charm combinations:

$$B^- \to l^- \bar{\nu} D^0 \text{ or } D^{*0},\ \bar{B}^0 \to l^- \bar{\nu} D^+ \text{ or } D^{*+}.$$

The lepton-D^{*+} combination comes only from $\bar{B}^0$, and the lepton-D^0 comes mostly from B^- decays. If the efficiency of the $D^{*+} \to D^0 \pi_s^+$ reconstruction, given a reconstructed D^0, is 100%, we can have a pure sample of D^0 which do not come from D^{*+}. In this case the separation of B^- and $\bar{B}^0$ is perfect. We have, however, to take into account the small contamination induced from the D^{**}. In figure 1(top left) the D^0 peak for the decay $K^-\pi^+$ is shown. The candidates that also qualify as D^{*+} are removed. The other three plots in figures 1 represent the distribution of the mass difference defined as $\Delta m = m(D^{*+}) - m(D^0)$. In this case the D^0 is identified as $K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$ and also as $K^-\rho^+$ with $\rho^+ \to \pi^+\pi^0$. In order to determine the B^- and B^0 lifetimes we perform a simultaneous fit to the four samples.The background lifetime shape is parametrized using the sidebands and the ‘wrong sign’ combination. The preliminary results are :

$$\tau(B^-) = 1.51 \pm 0.12(stat.) \pm 0.08(syst.) \text{ ps}$$

$$\tau(\bar{B}^0) = 1.57 \pm 0.08(stat.) \pm 0.08(syst.) \text{ ps}$$

and their ratio:

$$\tau(B^-)/\tau(\bar{B}^0) = 0.96 \pm 0.10(stat.) \pm 0.05(syst.)$$

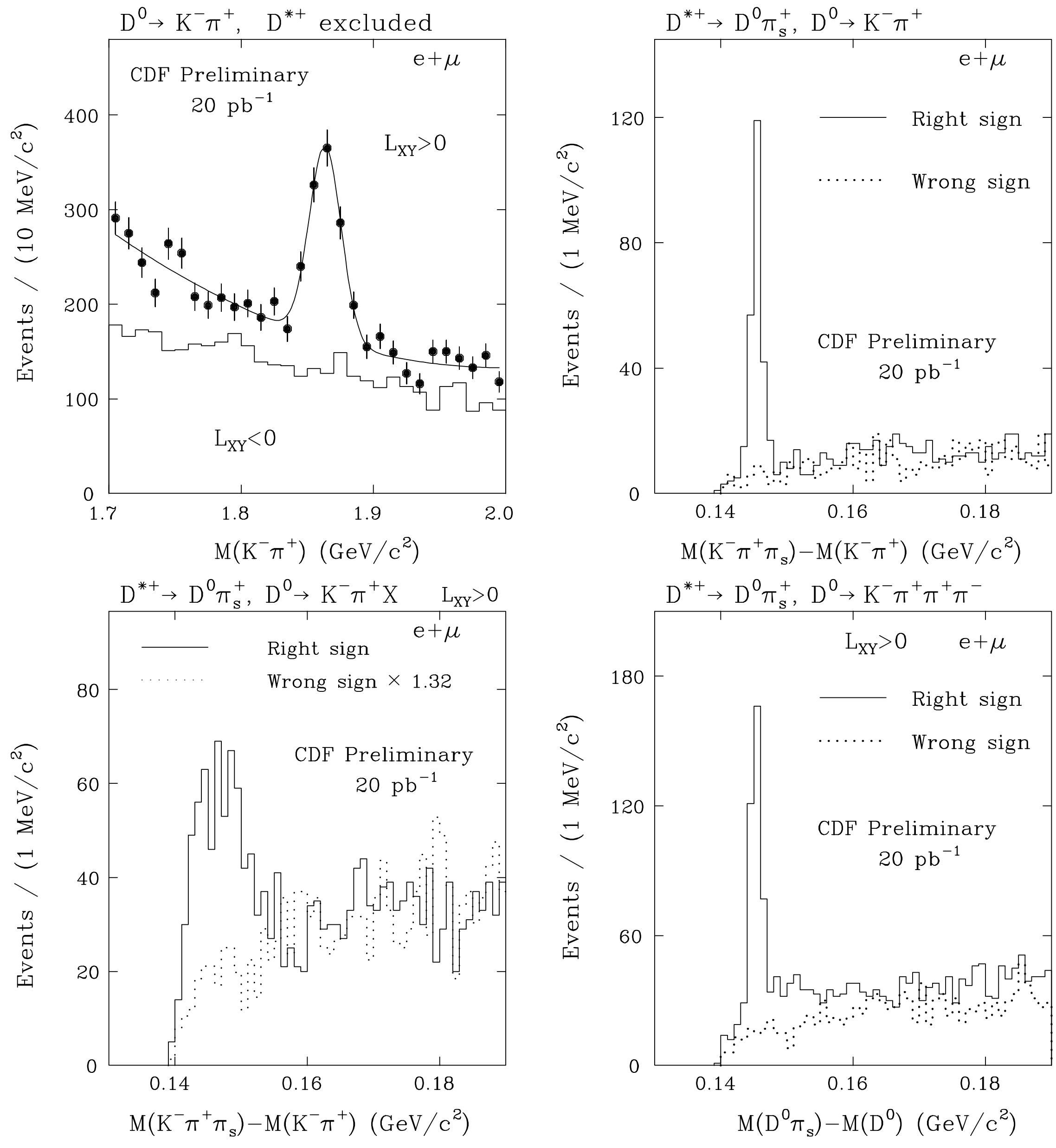

Figure 1: Charm signal mass peak for combined electron and muon sample. Different mode are shown.

2.2 B_s lifetime measurement

The B_s meson lifetime measurement is done exploiting the semileptonic decay $B_s \rightarrow l + D_s + X$, followed by $D_s^- \rightarrow \phi\pi^-, \phi \rightarrow K^+K^-$. The lepton here can be a muon or an electron. In figure 2, the $\phi\pi$ mass distribution is displayed. The upper plot shows the $\phi\pi^-$ invariant mass distribution

for the 'right-sign' lepton-D_s combinations. A D_s signal with a mean of 1.967 GeV/c^2 and a width of 5.4 MeV/c^2 is observed. Evidence of the Cabibbo suppressed $D^- \to \phi\pi^-$ decay is also present. No enhancement is seen in the corrisponding distribution for the 'wrong-sign' combination(lower plot). The signal region is defined using a D_s^- mass window of 1.953 to 1.981 GeV/c^2. A total of 139 events is found with a background fraction $f_{bg} = 0.45 \pm 0.01$. The number of $l\ D_s$ above background in the sample is 76 ± 8. Using the shaded regions to estimate the background shape, an unbinned likelihood fit to the sum of background plus signal is performed. The result of the fit is shown in figure 2.
The final number is $\tau(B_s) = 1.42^{+0.27}_{-0.23}(stat.) \pm 0.11(syst)$ ps [5].

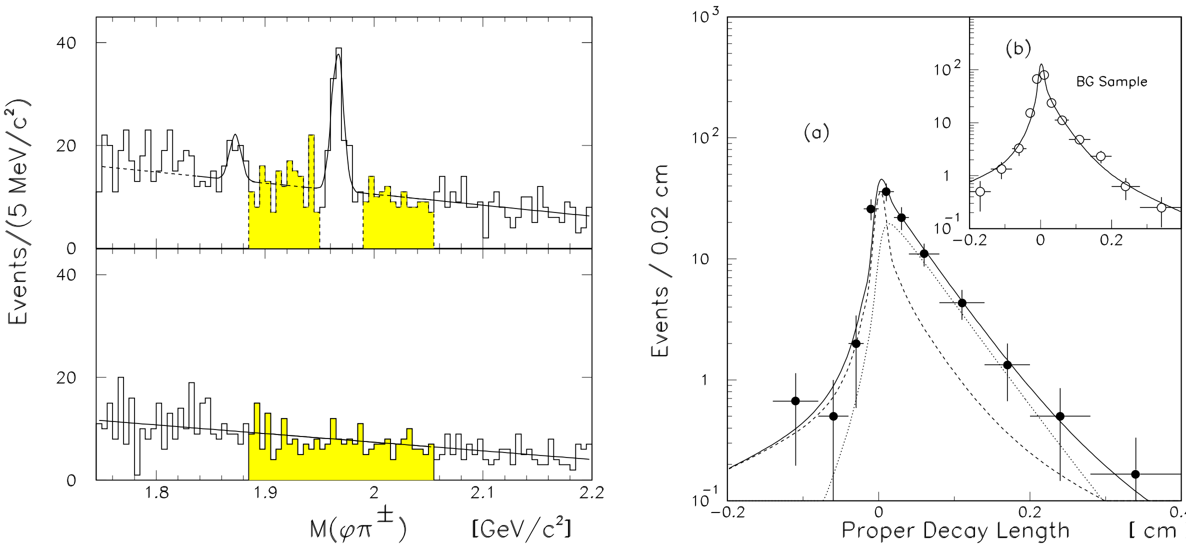

Figure 2: Left:The mass distribution for 'right-sign' combinations (top) and for 'wrong-sign' combination (bottom). Right: (a) Proper decay length distribution for the signal sample (dots) with a fit result superimposed (solid line). The dashed line represents the contribution from the combinatorial background and the dotted one the signal contribution. (b) Proper decay length distribution for the background sample.

3 Rare decays search

Rare B decays provide us a way to test the Standard Model against possible effects of heavy top quark, anomalous magnetic moment of the W and charged Higgs. Establishing low limits constrains these models tightly. CDF has searched for $B \to \mu\mu K^{\pm}$, $B \to \mu\mu K^{*}$ and $B^0 \to \mu^+\mu^-$.

The limit on the flavor-changing neutral current decays $B \to \mu\mu K^{\pm}$ and $B \to \mu\mu K^{*}$ is found by calibrating on known signal $B \to J\psi K^{(\pm,*)}$. The data set consists of dimuon events whose invariant mass is in the range 2.7 to 4.7 GeV/c^2. The mass spectrum is then divided into two regions, 3.017 to 3.177 GeV/c^2 (resonant) and 3.9 to 4.5 GeV/c^2 (non-resonant). The sidebands of the B peak are used to predict the background under the B mass peak. B peaks from both $B \to J\psi K^{(\pm,*)}$ and $B \to \mu\mu K$ decays are then compared to set a limit on the latter. The final results are:

$$BR(B \to \mu\mu K^{\pm}) < 5.8 \times 10^{-5} \quad \text{and} \quad BR(B \to \mu\mu K^{*}) < 10.4 \times 10^{-5} \text{ at } 90\% \text{ CL.}$$

Using the dimuon data set with the invariant mass between 4.9 and 5.8 GeV/c^2 CDF sets a new limit also on the $B^0_{d(s)} \to \mu^+\mu^-$. We find no B^0_d candidates in a mass window of [5.205,5.355] GeV/c^2 and 1 B^0_s candidates in a mass window of [5.300,5.450] GeV/c^2. Normalizing to our measured cross section $\sigma(B^+) = 2.06 \pm 0.27 \pm 0.43 \mu b$ for $p_t(B) > 6$ GeV/c and $|y(B)| < 1$ (where y is the rapidity), and assuming $\sigma(B^+) = \sigma(B^0_d) = 2\sigma(B^0_s)$ we find

$$BR(B^0_d \to \mu^+\mu^-) < 2.0 \times 10^{-6} \quad \text{and} \quad BR(B^0_s \to \mu^+\mu^-) < 6.8 \times 10^{-6} \text{ at } 90\% \text{ CL.}$$

4 $B^0 - \bar{B}^0$ mixing study

$B^0 - \bar{B}^0$ mixing is well established inside the Standard Model. The probability density that a meson created at $t = 0$ as B^0_q decays as $\bar{B}^0_q$ at time t is :

$$\mathcal{P}(t)_{\bar{B}^0_q} = \frac{1}{2\tau} e^{-\frac{t}{\tau}} (1 - \cos \Delta m_q t) \tag{1}$$

where τ is B^0 lifetime, the index q is d or s, the mass difference between the two mass eigenstates $\Delta m_q \propto |V_{tq} V^*_{tb}|$, the Cabibbo-Kobayashi-Maskawa matrix elements. Integrating (1) over the time we obtain the probability that a B^0 oscillates to a $\bar{B}^0$,

$$\chi_q = \frac{x_q^2}{2\left(1 + x_q^2\right)}$$

with the definition $x_q = \Delta m_q \cdot \tau$. For a mixing measurement, tagging the b content of both the $B-$hadrons is needed. The 'standard way' is detecting the flavour from semileptonic decay of B mesons. The lepton charge is directly correlated to the B flavour: $b \to l^- \bar{\nu} X$, $\bar{b} \to l^+ \nu X$. In dilepton events, same charge leptons can flag a $B^0 - \bar{B}^0$ mixing though background sources, represented mostly by sequential decays ($b \to c \to l$), prompt charm ($c \to l$) and Drell-Yan can diluite the effect.

4.1 Time integrated

Since a $p\bar{p}$ B^0_d and B^0_s can't be distinguished only the averaged mixing paremeter, $\bar{\chi}$ can be measured:

$$\bar{\chi} = f_d \chi_d + f_s \chi_s$$

where f_d and f_s are the fractions of B^0_d and B^0_s mesons in that samples. The ratio of like sign events (LS) to the opposite sign (OS), R can be written:

$$R = \frac{2\bar{\chi}(1-\bar{\chi}) + [(1-\bar{\chi})^2 + \bar{\chi}^2] f_{seq}}{(1-\bar{\chi})^2 + \bar{\chi}^2 + 2\bar{\chi}(1-\bar{\chi}) f_{seq} + f_c} \tag{2}$$

with f_{seq} equal to sequential decay fraction and f_c equal to prompt charm fraction.

CDF starting from a sample of $e\mu$ events after all selection criteria measures 1710 OS and 861 LS. The averaged mixing parameter is estimated:

$$\bar{\chi} = 0.118 \pm 0.008(stat.) \pm 0.020(syst.)$$

whith $f_{sec} = 0.186 \pm 0.034$ and $f_c = 0.041 \pm 0.014$.

D0 uses a sample of dimuon events that corresponds to about $10 pb^{-1}$ luminosity. The quoted value for R is

$$R = 0.49 \pm 0.08(stat.) \pm 0.05(syst.)$$

Applying the formula 2 we can extract $\bar{\chi}$. The final number is

$$\bar{\chi} = 0.13 \pm 0.05(stat.) \pm 0.04(syst.)$$

4.2 Time dependent

For this analysis a sample of dimuon events with a $p_t > 2$ GeV/c has been used. The B vertex is determined with an inclusive vertex technique. Excluding the muon, a charm vertex is searched for. The inferred charm track is vertexed with a muon in order to calculate the position of the B vertex. The so called pseudo-$c\tau$ is then: $\frac{L_{xy} \cdot m_B}{p_t^B}$. The transverse momentum of the B, p_t^B, is determined from the data and corrected using a Montecarlo simulation. The sequential decay fraction and the background is highly reduced by requiring the muon p_t^{rel} to the charm direction to be grater then 1.3 GeV/c. The final sample consists of 1516 LS events and 2357 OS events. In order to extract a mixing parameter x_d, a binned χ^2 fit is performed to the like sign fraction. The B_s^0 mixing is assumed to be maximal. The lifetime, τ, the B species fraction and the background fraction are constrained in the fit within gaussian errors. In particular $\tau = 1.46 \pm 0.06(stat.) \pm 0.06(syst.)$ [4]. The effect of sequential decays is taken into account. The results of the fit are shown in figure 3. The preliminary value quoted by CDF is

$$x_d = 0.64 \pm 0.18(stat.) \pm 0.21(syst.)$$

The systematic error is dominated from the uncertainty in the sequential decay fraction and we expect to reduce it by a factor of 2 in the near future.

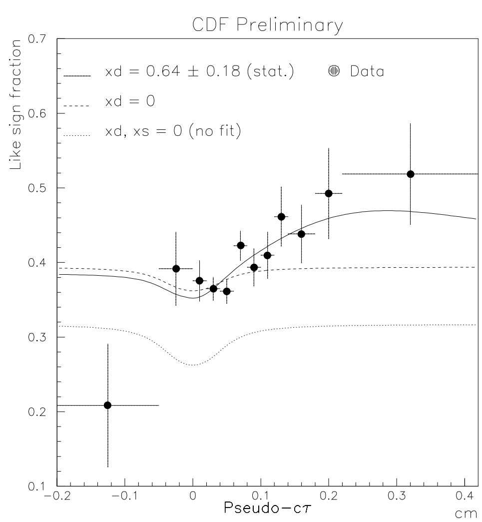

Figure 3: Like sign fraction distribution as a function of the reconstructed proper decay lenght.

Conclusions

A review of B lifetime measurements, B rare decays limits and $B^0 - \bar{B}^0$ mixing study has been presented. The Tevatron collider is still running and both the experiments, CDF and D0, are taking data since January 1994. We expext to decrease the statistical uncertainties in these measurements by at least factor of 2 with the new data sets.

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